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2-D Imaging of Concealed Objects using Circular Co-Arrays at MM Wave Frequencies: Simulation and Experimental Results

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ABSTRACT

Simulation and experiments conducted on RF imaging making use of co-located transmit and receive circular co-arrays are presented. Results obtained for 2-D imaging of a single target of unit reflectivity, a concrete pillar and a gun shaped object placed in the central region of 2-D scene, have been presented. Simulation program has been written in MATLAB to reconstruct the raw images using an improvised algorithm. Simulation and experimental results obtained at 35 GHz confirm the effectiveness of this method when used for RF imaging. Image of a Gun-shaped object has also been reconstructed by simulation and compared with experimental results. Images have been reconstructed using post data acquisition processing on the received signals. Experimental results confirm that the method can be used to reconstruct quality image for detection of concealed metallic objects using MM wave frequencies.

Keywords: Electromagnetic scattering, microwave millimeter wave imaging, RF imaging

1. INTRODUCTION

In recent years, inverse electromagnetic scattering and near field imaging have been widely studied research topics[1-4]. Microwave imaging may be successfully used as a diagnostic technique in several areas, for instance civil and industrial engineering, testing and evaluation of new materials, geophysical prospective and medicine[5, 6].Several methods of imaging with distributed sources have been investigated in the past. Most of these methods use synthetic aperture techniques or ultra wide band signals for 'through the wall imaging'[7-9]. A comparison of these methods has been made in terms of operating frequencies, image profile and image quality in Ankita[9], *et al*. The method of RF imaging being reported in this paper makes use of transmit and receive circular co-arrays co-located in a plane. This particular configuration was investigated as it provides ease of fabrication of imager resulting in planar profile. It uses a CW signal for transmission and the image is formed by post data processing of received signals. The basic concept of imaging in one dimension has been described in Fauzia Ahmad[10] *et al.* In this paper, we present simulation and experimental results on RF imaging using circular co-arrays, consisting of alternate transmitting and receiving elements.

Main aim of this work is to image a 2-D scene using microwave/ millimeter waves to detect concealed objects/ weapons. The detection of concealed objects is possible as the radiations at these frequencies can penetrate through clothes/ paper/ card board/ plastics and other sheets of dielectrics.

2. THEORY

A wideband synthetic aperture beam former for through-the-wall imaging has been described by Fauzia Ahmad[10] *et al*. In this work basic co-array based aperture synthesis scheme using linear sub-arrays and post data acquisition beam forming has been used. The scheme has been further extended for use in 2-D imaging using circular co-arrays[11]. A short description of the method of imaging used in simulations and experiments is reproduced here for better understanding.

The imager consists of M transmit/receive elements alternatively placed around the circumference of a circle of radius R in z=0 plane. The image plane is located at a distance Z from the origin in +z direction. It is divided into pxp number of pixels.

The process of imaging starts with transmission of a CW signal $s(t)$ from the first transmitting element and the scattered signals from various pixels of the scene are received by all the receiving elements present in the imager. The received signal by n^{th} receiving element, when m^{th} transmit element transmits, can be written as,

$$b_{mn}(t) = \sum_{pq} a_{pq}.s(t - \tau_{mnpq}) \quad (1)$$

where, a_{pq} = reflectivity of the target in the pixel P_{pq} and τ_{mnpq} = propagation delay encountered by the signal as it travels from the m^{th} transmitter to the target at the pixel P_{pq} and back to the n^{th} receiver. This delay is given by,

$$\tau_{mnpq} = \{d(Tx_m, P_{pq}) + d(P_{pq}, Rx_n)\} / c \quad (2)$$

where, c = speed of light and $d\ (x,\ y)$ = distance between

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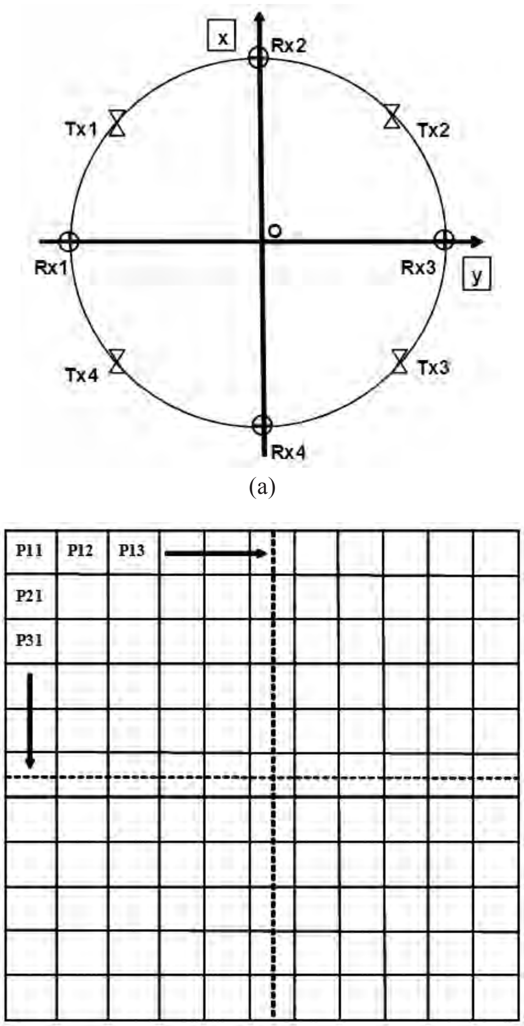


(a)

(b)

Figure 1. (a) Locations of Tx and Rx elements in circular 4x4 array and (b) Image plane located at a distance Z from the origin in z direction.

locations *x* and *y*. Complete scene is illuminated by all *M* transmitters located at the locations Tx_m sequentially and for each transmitter the signal is received by *M* receivers located at the locations Rx_n.

Image intensity in various pixels can be obtained by summing the *M* received signals after applying phase corrections as given by

$$Z_{mpq}(t) = \sum_{n=1}^{M} w_{rn}.\sum_{pq} a_{pq}.s(t - \tau_{mnpq} - \bar{\tau}_{mnpq}) \quad (3)$$

$$\tau_{mnpq} = \{2R_{pq} - d(Tx_m, P_{pq}) - d(P_{pq}, Rx_n)\} / c$$

where, w_{rn} = weight applied to the output of the n^{th} receiver and $\bar{\tau}_{mnpq}$ = focusing delay corresponding to the pixel P_{pq} applied to the output of the n^{th} receiver when the transmitter is at the m^{th} location.

The focusing delay corrects the received signals by appropriate phase before they are combined to calculate the intensity in each pixel. The process is repeated for all *M* composite signals. The amplitude for each pixel of the image P_{pq} is obtained as,

$$A(P_{pq}) = \{\sum_{m=1}^{M} w_{tm}.z_{mpq}(t)\}_{t\ =\ 2R_{pq}\ /\ c} \quad (4)$$

where, w_{tm} = weight applied to the component signal z_{mpq} (*t*) obtained using the m^{th} transmitter. The intensity matrix corresponding to each pixel in logarithmic scale is given by,

$$I(P_{pq}) = 20\log\{A(P_{pq})\} \quad (5)$$

A program has been written in MATLAB to reconstruct the raw image. The program simulates the target scene by placing targets in different pixels of the scene and reconstructs the image by calculating the intensities in each pixel as given in Eqn (5). Target is assumed to be placed in overlapping field of view of transmitting and receiving elements. Simulation and experiments have been done for a 2-D scene containing a single stationary target resembling a corner reflector, a target resembling a vertical pole and a target resembling a gun with a reflection coefficient of unity.

3. EXPERIMENTAL DETAILS

The imaging process was verified using experimental results. Two Ka-band horn antennas (having 3 dB beam width of 10°) were used as transmit and receive elements. Scattering parameter S_{21} was measured at different locations of the receiving elements while keeping the transmit horn at a fixed location. These measurements were then repeated for all locations of the transmit horn sequentially. The transmitting and receiving horns were moved to different locations along the circumference of a circle of radius 0.4 m with the help of a motor. The polarisation of both the horns was matched at each location before collecting the data. Rohde & Schwarz Vector Network Analyser ZVK was used to measure scattering parameter S_{21} at 35 GHz. Measurements were taken for different targets after placing the targets at a fixed distance of 5.1 m. Distance of 5.1 m was specially selected for these experiments so that the targets placed are always in the overlapping beams of transmitting and receiving horn antennas. As the maximum power available for transmission from the network analyser port was 0 dBm, targets could not be placed at larger distances in order to receive the signal within the sensitivity of network analyser. The targets used in these measurements were, a square corner reflector of size 0.16 m x 0.16 m, a vertical concrete pillar of dia 0.254 m and height 3 m and a metallic sheet of size 0.18 m x 0.13 m cut into the shape of a gun. Images have been reconstructed using the software developed in MATLAB and the measurement data collected using network analyser. Figure 2 shows the experimental setup for measurement of scattered radiation.

4. RESULTS AND DISCUSSION

4.1 Simulation Results

Simulation has been carried out for circular arrays in which alternate transmitting and receiving elements have been placed symmetrically on the circumference of a circle of radius 0.4 m.

Figures 3-5 show the results of simulation for three different types of targets placed in the scene.

Here, number of transmitting and receiving elements used M = 18, the distance of the scene from the array plane is, Z = 5.1m, the number of pixels in the 2-D square scene are 99 x 99, the

Figure 2. Experimental setup for measurement of scattered radiation.

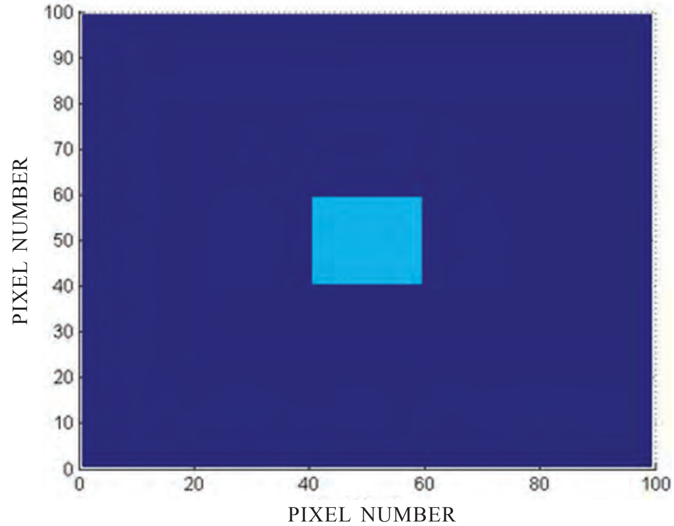
length and width of the square scene is, L = 0.9 m. Targets have been placed in the center of the scene. The frequency used is 35 GHz.

4.2 Experimental Results

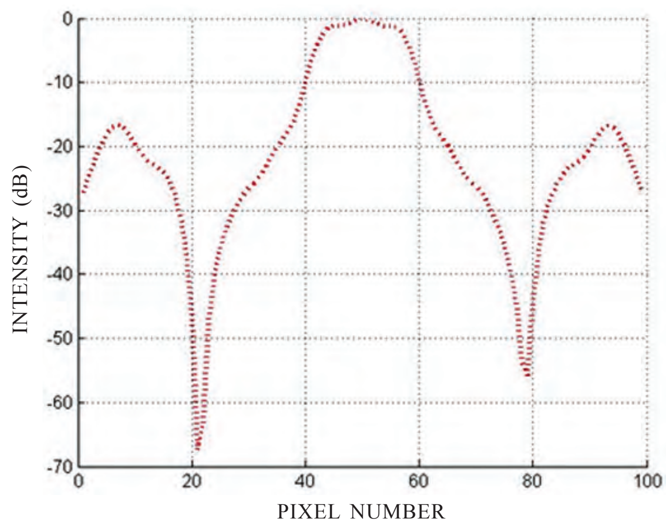
The experimental results presented in Figs. 6-8 are also for a circular array formed by rotating the receive horn in a circular path of radius 0.4 m for a given transmit location, as explained earlier, collecting the data at all receive locations and repeating the experiment for all transmit locations sequentially. All other parameters have also been kept same i.e. M = 18, the number of pixels in the 2-D square scene are 99 x 99, Z = 5.1 m. The frequency used is 35 GHz.

The corner reflector, the Concrete pillar and the Gun-shaped object were covered with a 3 mm thick dry canvas before collecting the experimental data as the aim of this experiment was to detect concealed objects using circular co-arrays. From these figures, it is clear that the shape of the objects can be detected and the algorithm may be used to detect concealed objects after taking care of attenuation factor of the concealing material.

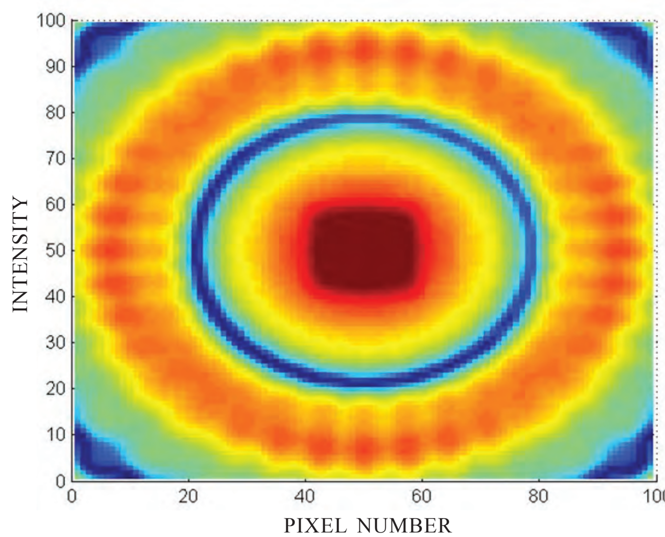
Simulated as well as experimental images show the presence of a circular ring around the object being imaged. This is nothing but the first maxima of the synthesised pattern which appears as a circular ring since a circular co-array is being used for imaging. The imaging area is therefore restricted by this circular ring. When the imager is used to image, a large object like a pillar, the full height of the pillar extends beyond the restricted imaging area. Therefore the full height of pillar does not appear in the simulated as well as experimental image formed after post data acquisition. This problem can be taken care by carefully selecting the number of transmit and receive elements and the radius of the array, at a given frequency, to push away the first Maxima resulting into large permissible



(a)



(b)



(c)

Figure 3. (a) Simulated single target (corner reflector of size 0.16 m x 0.16 m) in the scene, (b) Plot of intensity versus pixel number in central row after post data processing, and (c) Reconstructed raw image after post data processing.

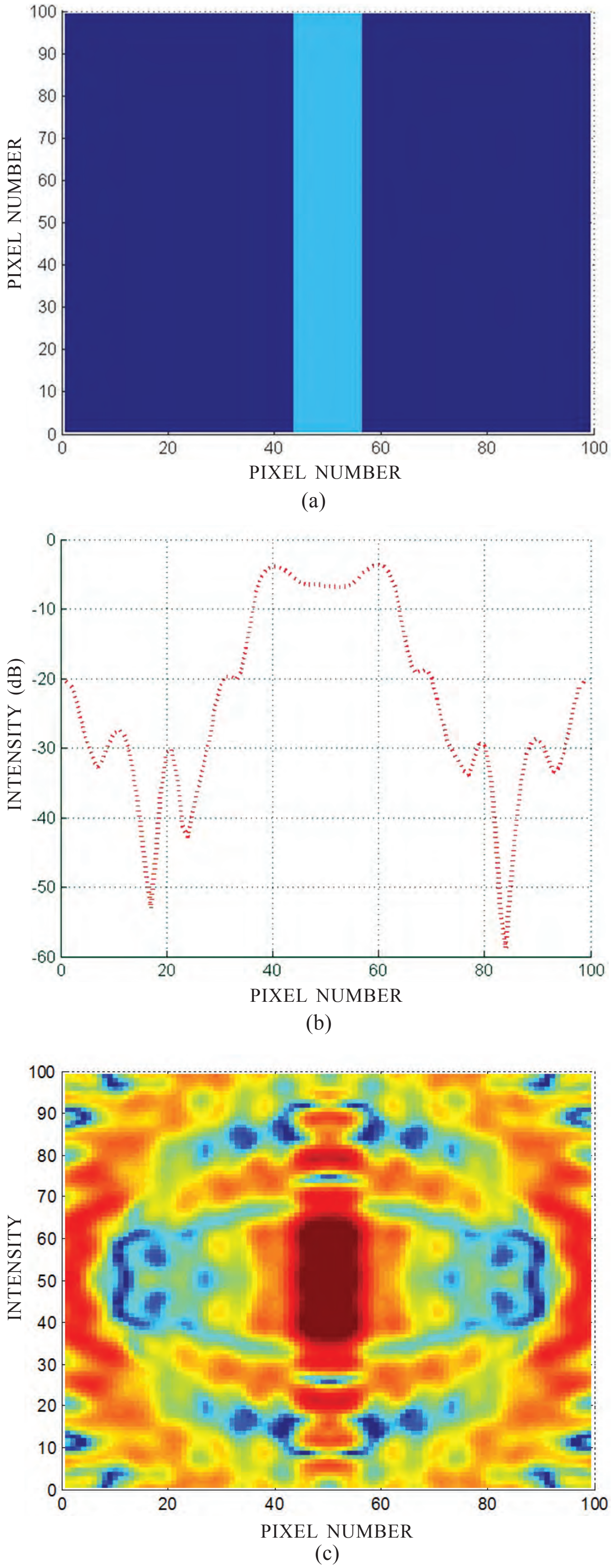


Figure 4. (a) Simulated pillar (0.254 m dia, 0.89 m) in the scene, (b) Plot of intensity versus pixel number in central row after post data processing, and(c) Reconstructed raw image after post data processing.

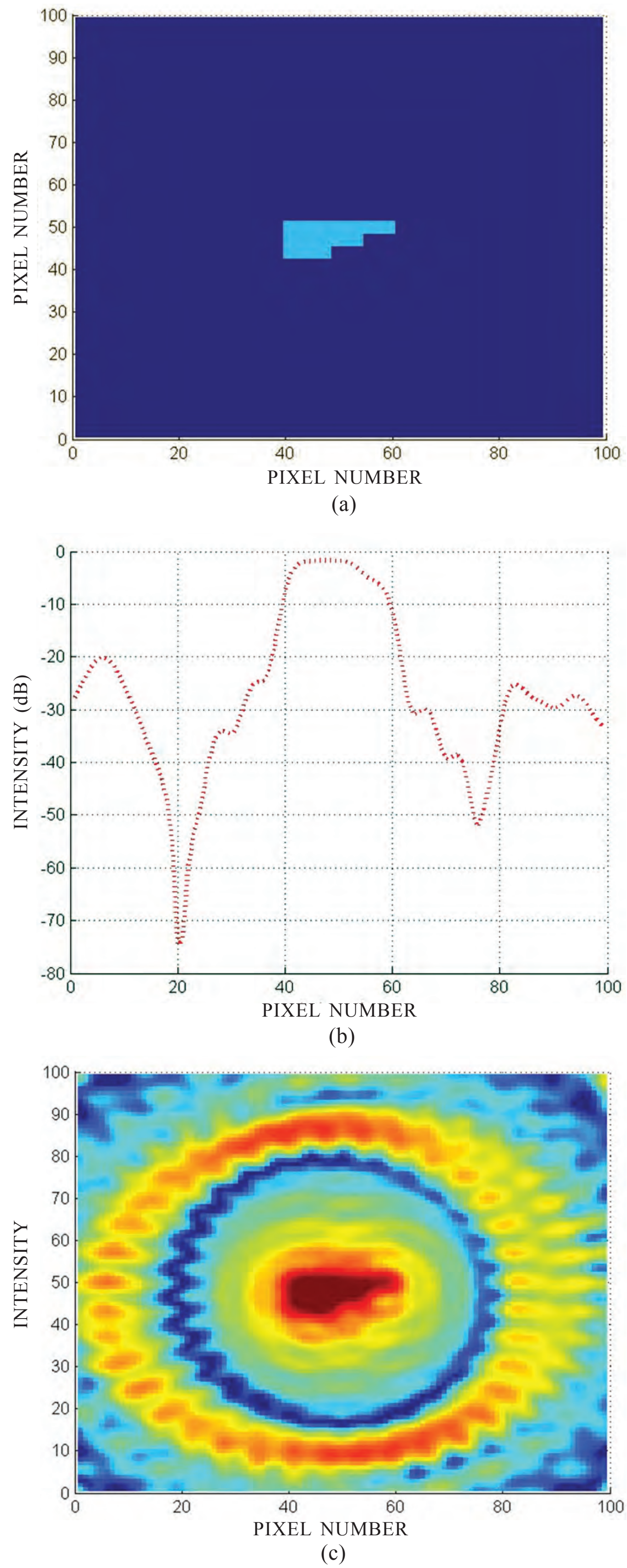


Figure 5. (a) Simulated Gun-shaped target (cut out of metal sheet of size 0.18 m x 0.13 m) in the scene, (b) Plot of intensity versus pixel number in central row after post data processing, and (c) Reconstructed raw image after post data processing.

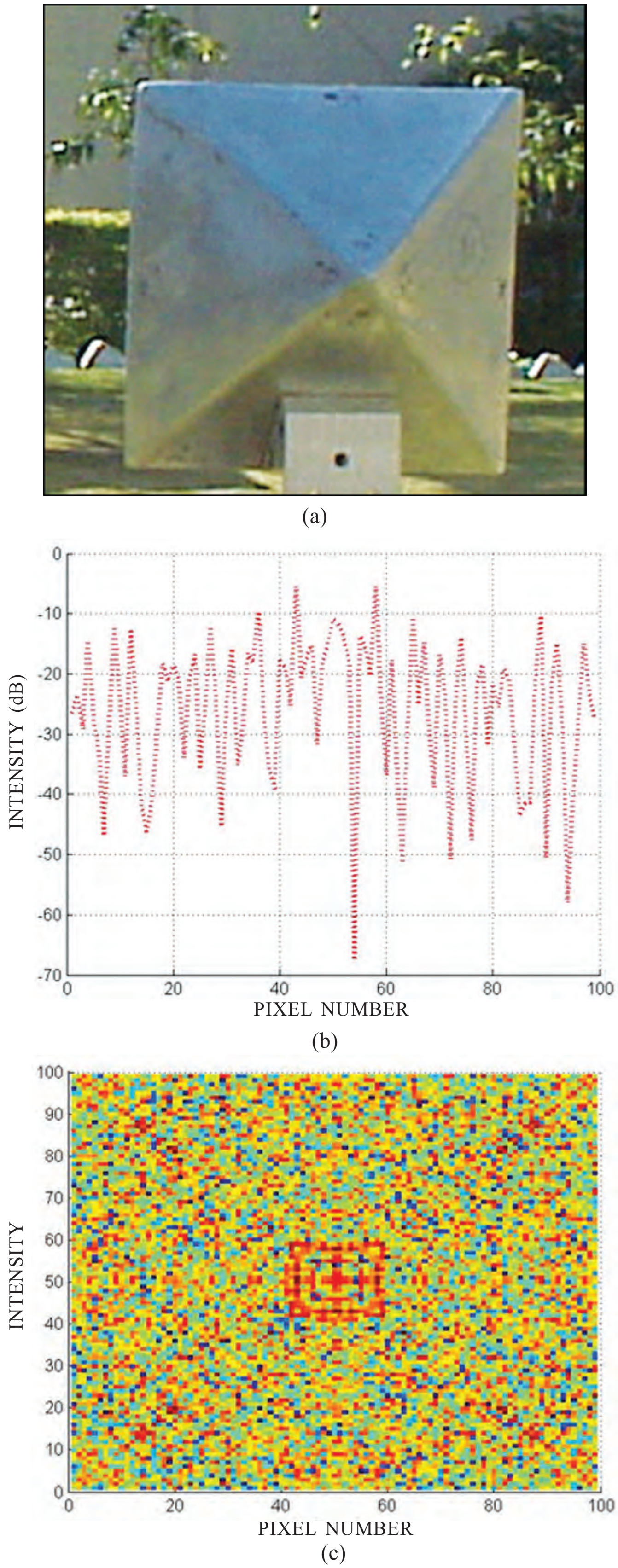


Figure 6. (a) Single target (corner reflector of size 0.16 m x 0.16 m) in the scene, (b) Plot of intensity versus pixel number in central row after post data processing, and (c) Reconstructed raw image after post data processing constructed using experimental data.

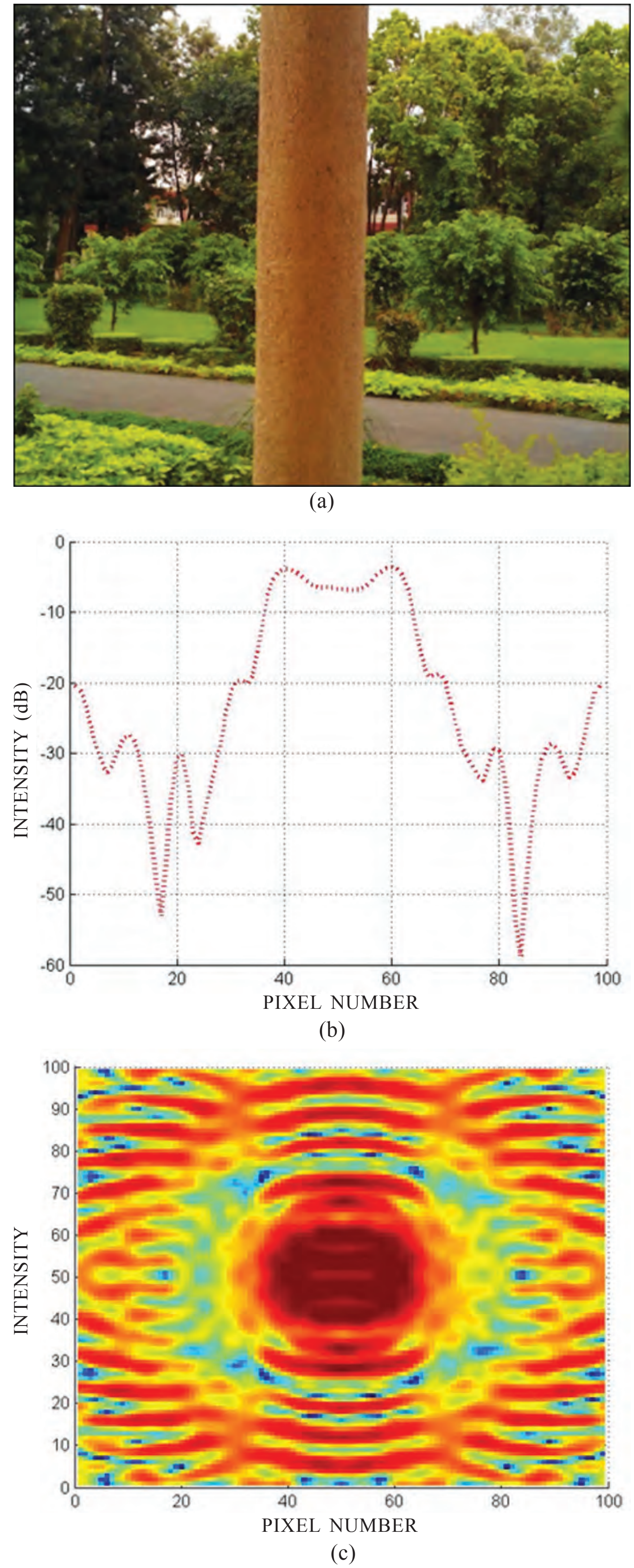
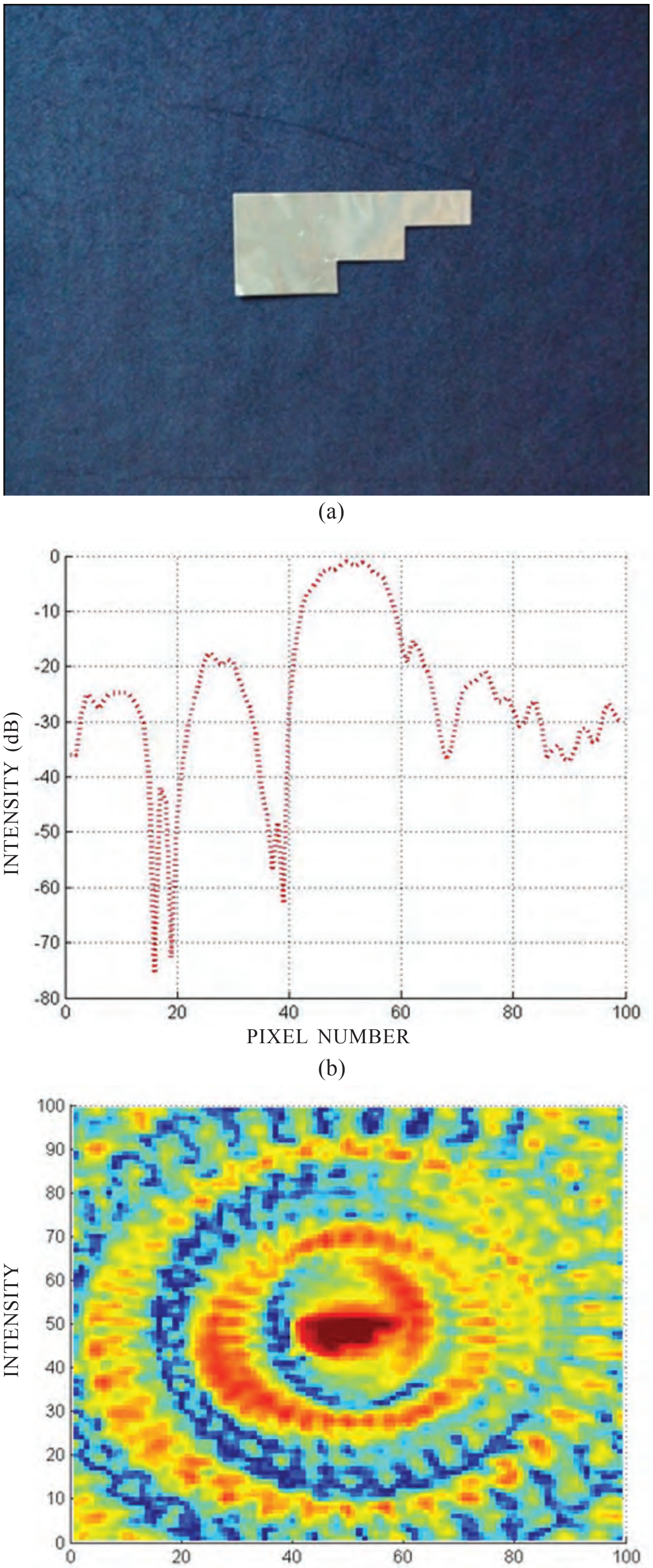


Figure 7. (a) Concrete pillar (0.254 m dia, 3 m) in the scene, (b) Plot of intensity versus pixel number in central row after post data processing, and (c) Reconstructed raw image after post data processing constructed using experimental data.



(a)

(b)

(c)

Figure 8. (a) Gun-shaped target (cut out of metal sheet of size 0.18 m x 0.13 m) in the scene, (b) Plot of intensity versus pixel number in central row after post data processing, and (c) Reconstructed raw image after post data processing constructed using experimental data.

imaging area. However, it is also important to note that the finer contours of the target can be imaged by very narrow synthetic beam, at a given frequency, which requires the use of large numbers of transmit and receive elements placed around a circle having large value of radius R. The Lower limit on the target size that can be imaged is set by the sharpness of the synthetic aperture beam produced, which in turn depends on the number of transmit and receive elements, the radius of the array, and the operating frequency used. The Upper limit on the target size is, however, set by the appearance of first maxima in synthesised pattern. A Practical solution for imaging small objects with finer details and bigger objects with less precision simultaneously, may be found in using more than one co-centered arrays of different radii and different number of transmit and receive elements in the plane of the imager.

This process of imaging may not be highly suitable for exact measurement of the sizes of the objects, however the sizes of the objects in reconstructed images are close to the actual sizes. This is because the images formed by synthetic aperture imaging, at higher frequencies, are more prone to get affected by scattering at the corners of the objects. However the shape of the objects can be detected

Although due care was taken in aligning the centre of the imaging array with the centre of the image plane, measuring the distance of image plane from the centre of the array, aligning the aperture of the corner reflector perpendicular to z direction, using a motorised system to accurately place transmit and receive horns at required locations and aligning the polarisation of the horns to the best possible, the error in all these alignments had a definite effect on the images created using experimental data. The fluctuations in the measurement of the phase due to atmospheric turbulence were also observed during measurements. This has also contributed to the errors in measurement and therefore the experimental images are not as sharp as the simulated ones.

5. CONCLUSIONS

Simulation results show that the circular transmit and receive co-arrays located in the plane of the imager can be used for RF imaging. This method of imaging can be used to produce very compact imagers at Millimeter wave frequencies. Objects of various shapes and sizes have been simulated and images have been formed. With the use of circular co-arrays of different sizes and different number of transmit and receive elements, in a given operating frequency, the quality of images may be improved in terms of resolution, shape and sizes of the objects. The method of reconstruction of raw image of 2-D scene has been successfully tested using single frequency CW source by conducting experiments at 35 GHz. Preliminary experimental results show that the method can be used for reconstruction of quality images.

Experiments have also proved the effectiveness of this method for concealed weapon detection.

REFERENCES

1. Cheng, Binbin; Jiang, Ge; Wang, Cheng; Yang, Chen; Cai, Yingwu; Chen, Qi; Huang, Xiang; Zeng, Genghua; Jiang, Jun; Deng, Xianjin & Zhang, Jian. Real-time imaging

with a 140 GHz inverse synthetic aperture radar. *IEEE Trans. Terahertz Sci. Technol.*, 2013, **3**(5), 594-605.
doi: 10.1109/TTHZ.2013.2268317
2. Bolomey, J. C. & Jofre, L. Three decades of active microwave imaging achievements, difficulties and future challenges. IEEE International Conference on Wireless Information Technology and Systems, ICWITS 2010, Honolulu, HI, USA, pp.1-4.
doi: 10.1109/ICWITS.2010.5611904
3. Li, LiangChao; Yang, JianYu; Cui, GuoLong; Jiang, ZhengMao & Zheng, Xin. Method of passive MMW image detection and identification for close target. *J. Infrared Milli Terahz Waves*, 2011, **32**, 102-115.
doi: 10.1007/s10762-010-9744-7
4. Demirci, Sevket & Ozdemir, Caner. Compressed sensing-based imaging of millimeter-wave ISAR data. *Microwave Opt. Technol. Lett.*, 2013, **55**(12), 2967-2972.
5. Pastorino, M. Microwave imaging, John Willey and Sons Publication, New York, 2010, pp.1-53.
doi: 10.1002/9780470602492
6. Gragnani, Gian Luigi. Closed-form method for the reconstruction of 2-D objects: preliminary experimental results. *Int. J. RF Microwave Comput. Aided Eng.*, 2013, **23**(4), 482-487.
doi: 10.1002/mmce.20738
7. Wang, Yazhou; Yang, Yunqiang & Fathy, Aly E. Reconfigurable ultra-wide band see-through-wall imaging radar system. Antennas and Propagation Society International Symposium, 2009, pp.1-4.
doi: 10.1109/aps.2009.5171851
8. Wang,Yazhou; Yang, Yunqiang & Fathy, Aly E. A reconfigurable UWB system for real-time through wall imaging applications. Radio and Wireless Symposium (RWS*)*, 2010, 633-636.
doi: 10.1109/rws.2010.5434156
9. Ankita; Basu, Ananjan. Microwave imaging using distributed sensors. International Microwave and RF Conference, IEEE MTT-S, 2013, pp. 1-4.
doi: 10.1109/imarc.2013.6777747
10. Ahmad, Fauzia; Amin, Moeness G.; Kassam, Saleem A. & Frazer, Gordan J. A wideband synthetic aperture beamformer for through-the-wall imaging. IEEE International Symposium on Phased Array System and Technology 2003, pp.187-192.
doi: 10.1109/past.2003.1256979
11. Dixit, R. P.; Sharma, Kiran & Jain, S. C. Co-array based synthetic aperture active imaging at millimeter wave frequencies. Accepted for publication in IETE Journal of Research.
doi: 10.1080/03772063.2015.1082441

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